

Detecting minijet production in $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions with multi-particle transverse energy correlation functions

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Multi-particle transverse energy correlation(MTEC) functions are proposed to study minijet production in high energy $p\bar{p}$ collisions. Obtainable with both the D0 and the CDF detector, the high-order MTEC functions are shown to be sensitive probes of jet internal structure as well as promising observables of detecting minijet production in $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions.

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That the non-perturbative component of jet observables is suppressed by some inverse power of the jet energy is one of the main properties of the jet observables, ensuing from their infrared and collinear safety [1]. Hence observables of minijet production initiated by parton with transverse energy $E_T \leq 5$ GeV and calculable at the parton level as high energy jet, are definitely much more useful than those of high energy jet for the study of non-perturbative effects. Therefore detection of minijet production, as a first step toward the measurement of minijet complementary to the measurement of high energy jet, will open another window of testing QCD, in addition to the study of high energy jet [2], the finding of new particles [3] and the determining of strong coupling constant α_s with high precision [4].

Having been found to play an important role to explain data of hadronic interactions [5,6], minijets have also been expected [7,8] to be copiously produced in the pre-equilibrium stage of ultra-relativistic heavy-ion collisions and their interactions dominate transverse energy production in the central rapidity region. However, before convincing evidence of minijet production is reported, one can not exclude that other mechanisms such as expanding quark-gluon plasma [9] or soft production [10] instead of minijet production play the trick. Therefore, detection of minijet production is of great importance not only to the elementary particle physics but also to the physics of high energy nucleus-nucleus collisions.

Unfortunately, minijets can not be identified directly with the successful and well developed jet-finding algorithms [11,12], because the fluctuations of background are large enough to swamp signatures of minijet production. For this reason, no convincing evidence of minijet production has been reported yet. Recently, high-

order multi-particle transverse momentum correlation functions [13,14] are shown to be promising observables of detecting minijet production in $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions. However, the functions with the transverse momenta of particles in an event as variables, may be obtained with the CDF detector [15] and surely can not be obtained with the D0 detector [16]. This is because the D0 detector has been designed to measure the polar angle θ , the azimuthal angle ϕ and the energy E for most of the particles in an event, while the CDF detector to measure also the momentum P . The purpose of this paper is to introduce a new method that can be used for the study of minijet production with both the D0 and the CDF detector, and then to study the possibility of detecting minijet production in $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions.

Originally designed for the study of transverse collective flow in heavy-ion collisions at intermediate energies, multi-particle transverse momentum correlation functions [13,14] show promise of signaling minijet production in high energy $p\bar{p}$ collisions because the preferential emission pattern [17,18] of a jet is similar to that of sideward collective flow in heavy-ion collisions resulted from the compressed nuclear matter, while that kind of matter can not be produced in the $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions, and also because one can not expect a preferential emission pattern from the expanding quark-gluon plasma [9] or soft production [10] as stated in Ref. [19]. As for the similarity, one is referred to Refs. [20,21], in which it was reported that the sphericity analysis [20] of jet production in high energy e^+e^- collisions was generalized to analyze data of heavy-ion collisions and led to the first observation [21] of collective flow in intermediate energy heavy-ion collisions. From the similarity it can be inferred that this preferential emission pattern, if projected on to a plane perpendicular to the beam direction, will induce not only multi-particle transverse momentum correlations which are similar to those observed in heavy-ion collisions [13], but also multi-particle transverse energy correlations. In this paper, the MTEC functions are proposed to study minijet production in high energy $p\bar{p}$ collisions from the point of view that energy preferential emission characterizes jet inner structure. It is demonstrated that high-order MTEC functions that can be obtained with both the D0 and the CDF detector are sensitive probes of jet internal structure as well as promising observables of detecting minijet production in $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions.

The MTEC functions for a sample of collision events

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can be calculated following three steps listed below. First of all, select N -particle sub-events from an event of multiplicity M and calculate the following variable for each of the sub-events

$$U_N = \frac{|\sum_{i=1}^N \vec{E}_T^i|}{\sum_{i=1}^N E_T^i}, \quad N \leq M, \quad (1)$$

where \vec{E}_T^i is defined as transverse energy vector for the i th particle in the sub-event, and the E_T^i is its magnitude. With \hat{x} and \hat{y} representing the unit vectors for x and y coordinates, the \vec{E}_T^i for the i th particle in the sub-event is expressed with its polar angle θ_i , azimuthal angle ϕ_i and energy E_i as following:

$$\vec{E}_T^i = E_i \sin\theta_i (\cos\phi_i \hat{x} + \sin\phi_i \hat{y}), \quad (2)$$

Secondly, calculate distribution function $D(U_N)$ of sub-events selected from collision events and distribution function $B(U_N)$ of sub-events selected from background events. Finally, calculate N -particle transverse energy correlation function $F(U_N)$ via its definition

$$F(U_N) = \frac{D(U_N)}{B(U_N)}, \quad (3)$$

For a given collision event, one of its background events is obtained in the following way [13,14]: resetting randomly the azimuthal angle for each of the M particles between 0 and 2π with both the polar angle and the energy (or the magnitude of the momentum vector) of the particle unchanged. In such constructed background events, there are no multi-particle transverse energy correlations caused by minijet production.

The sample of events used for the calculation of $F(U_N)$ usually contains a wide range of multiplicities M , and the number of entries an event contributes to the $D(U_N)$ and $B(U_N)$ histograms scales as $g = M!/(M-N)!N!$. Consequently, at some values of N , contributions from events with higher M completely swamp those with lower M if all the entries have equal weight. To compensate for this, the contribution from an event with multiplicity M is weighted by M/g , thus ensuring that each event makes a contribution to the final result that is proportional to the multiplicity M of the event [13,14].

According to Eq. (1), one can calculate $F(U_N)$ whenever θ , ϕ and E , whether or not P for each of the emitted particles in an event are measured. Therefore, the MTEC functions are obtainable with both of the two detectors the D0 and the CDF currently available at FERMILAB.

Next, we present a brief introduction of the Monte-Carlo model HIJING [22] used in the following to generate a sample of events for our analysis. Combining a QCD inspired model for jet production with the Lund model [23] for jet fragmentation, the formulation of HIJING was guided by the Lund FRITIOF [24] and Dual Parton Model [25] for soft processes and, the successful implementation of perturbative QCD processes in

PYTHIA [26,27] model for hadronic collisions. Based on the assumption of independent production of multiple minijets, the QCD inspired model determines the number of minijets per nucleon-nucleon collisions. For each hard or semihard interaction the kinetic variables of the scattered partons are determined by calling PYTHIA [27] subroutines. The scheme for the accompanying soft interactions is similar to FRITIOF model [24]. Fragmentation subroutine of JETSET [28] is called for hadronization. It has been reported [29] that HIJING can consistently reproduce many aspects of multi-particle production in pp and $p\bar{p}$ collisions at energies of $\sqrt{s} = 20$ GeV to $\sqrt{s} = 1.8$ TeV. Because HIJING code includes minijet production in the above mentioned way, it can be served as a theoretical laboratory of testifying the MTEC functions as probes of minijet production in high energy $p\bar{p}$ collisions.

The sample of events (SES), with which we study minijet production in high energy $p\bar{p}$ collisions are obtained in the following way [14]. First, generate a sample of minimum biased events of $\sqrt{s} = 1.8$ TeV $p\bar{p}$ collisions using HIJING1.2 code with default parameters. Second, drop off every high energy jet event in which at least one high energy jet with transverse energy larger than 5 GeV is produced, and the remaining events form the SES. In fact, two types of events comprise the SES. One type of events (NJPES) has neither high energy jet production nor minijet production, and the other type of events (MJPES) has minijet production but no high energy jet production. The experimental counterpart of the SES can be obtained following the same steps stated above with the aid of the widely used jet-finding algorithms [11,12] of finding high energy jet.

Our study in this paper is based on 10^6 Monte-Carlo events of minimum biased $\sqrt{s} = 1.8$ TeV $p\bar{p}$ collisions, from which a SES of about 491320 events is collected via the above scheme. Because in the CMS frame of the $p\bar{p}$ collisions minijet production and particle production in the forward hemisphere (*i.e.*, $\eta > 0$, $0 \leq \phi < 2\pi$) are both symmetry to those in the backward hemisphere (*i.e.*, $\eta < 0$, $0 \leq \phi < 2\pi$), and additionally the width of jet profiles is about 1 in pseudorapidity [30], our analysis are focused on charged particles with $0 \leq \eta \leq 1$, $0 \leq \phi < 2\pi$. As a result, about 438400 events of the SES are at our disposal, among which about 131102 events constitute the NJPES and the other events about 307298 form the MJPES actually used in the following analysis.

Fig. 1 shows HIJING1.2 results of the MTEC function $F(U_N)$ in the NJPES of the SES. As shown in Fig. 1, N -particle transverse energy correlation function $F(U_N) \simeq 1$ for the NJPES, both with and without transverse energy cuts. These results demonstrate that transverse energy is uniformly distributed in azimuthal angle in the central region $0 \leq \eta \leq 1$ of the NJPES where no jets are produced.

Fig. 2 shows HIJING1.2 results of the MTEC function

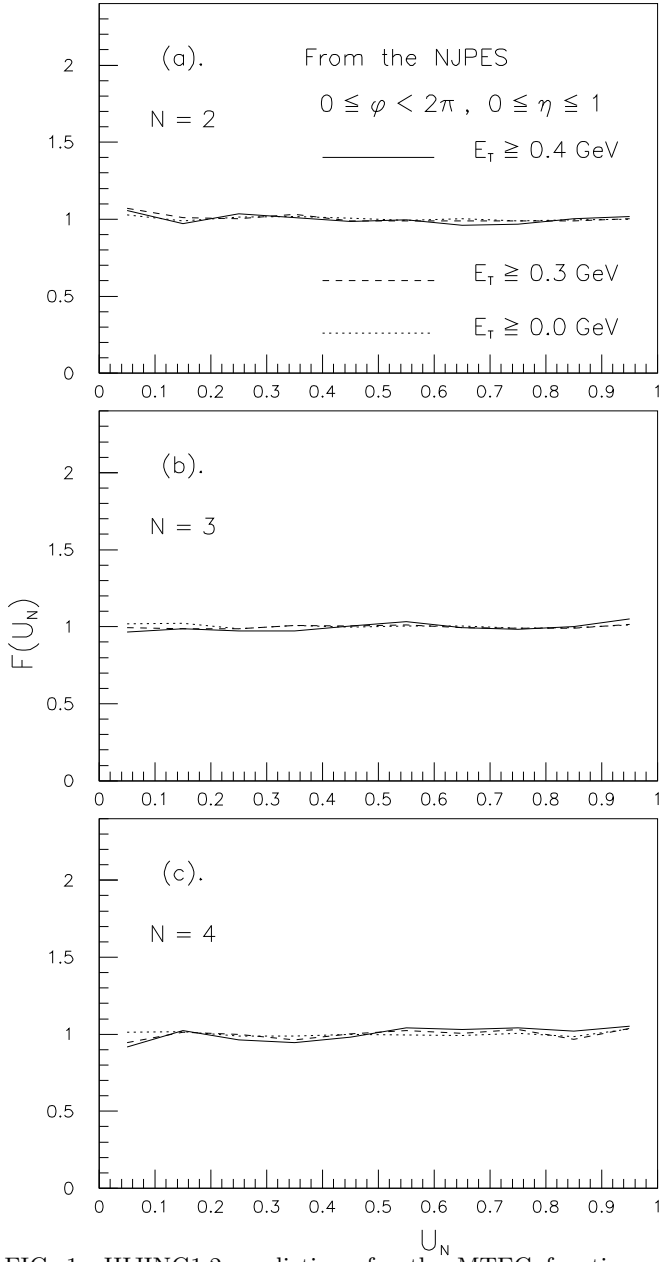


FIG. 1. HIJING1.2 predictions for the MTEC function $F(U_N)$ in the NJPES of the SES selected from $\sqrt{s} = 1.8$ TeV minimum biased $p\bar{p}$ collision events.

$F(U_N)$ in the SES with and without transverse energy cuts. First of all, deviations of $F(U_N)$ from 1 appear, *i.e.*, enhancement of $F(U_N)$ near the region of $U_N = 1$ and hence the systematic suppression of $F(U_N)$ in other regions of U_N . Comparing with the results shown in Fig. 1, one can conclude that these deviations are solely determined by the MJPES of the SES and can be inferred to be an indication of minijet production in the SES of the minimum biased collision events. The deviations characterized by both the enhancement and the suppression of $F(U_N)$ as shown in Fig. 2 result from the preferential energy flow induced by minijet production, which definitely enhances (suppresses) the probability of finding

sub-event with high (low) values of U_N in the collision events compared to that in the background events where no preferential energy flow can be expected. Secondly, one can see from Fig. 2 that with the increase of sub-event multiplicity N , the above mentioned deviations of the MTEC function $F(U_N)$ from 1 become larger. A collateral statement is that minijet production can be detected more clearly through high-order MTEC functions than through two-particle transverse energy correlation function. This feature of MTEC functions is originated

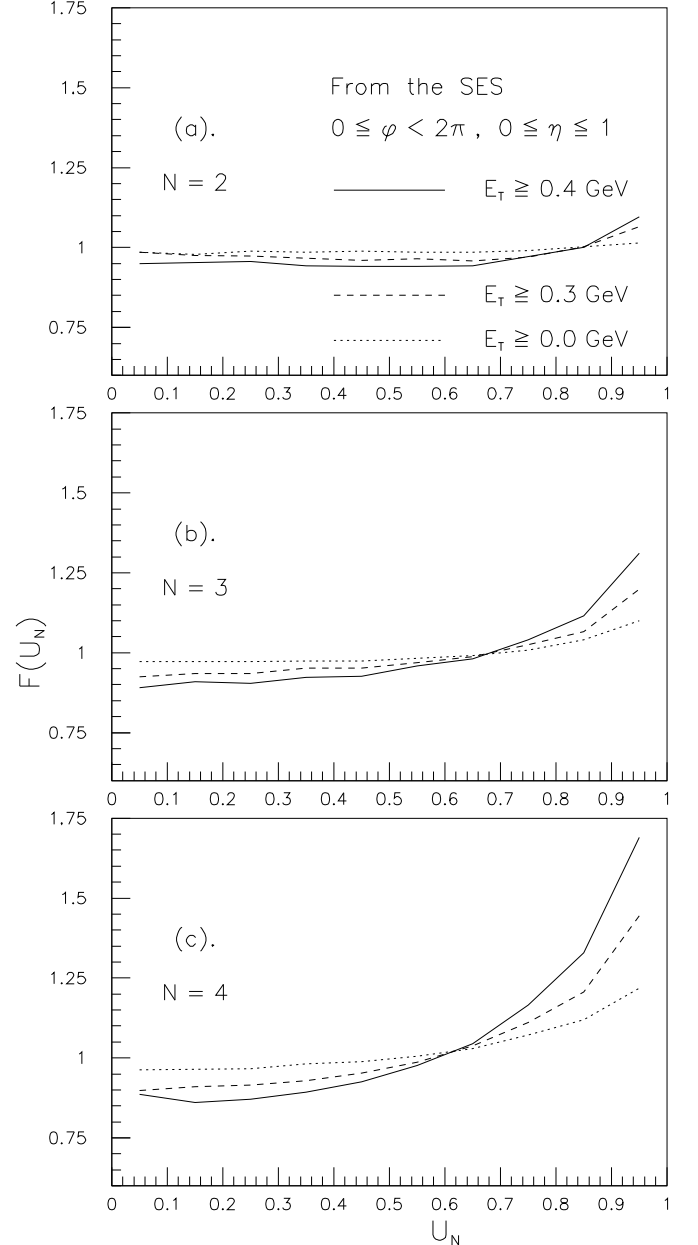


FIG. 2. HIJING1.2 predictions for the MTEC function $F(U_N)$ in the SES of $\sqrt{s}=1.8$ TeV minimum biased $p\bar{p}$ collision events.

from the collective energy flow of the preferential emission pattern of jet production or in other words the collec-

tive aspect of collinearity property of jet inner structure. The two-particle transverse energy correlation function reflects this facet of jet property, however not as complete as the high-order MTEC functions do. Thirdly, Fig. 2 also signifies that $F(U_N)$ calculated from charged particles with a larger transverse energy cut displays much more evident enhancement and suppression mentioned above than those with a smaller transverse energy cut. This feature of $F(U_N)$ shows that particles with higher transverse energy are more preferentially emitted along the jet axis than those with low transverse energy, hence a reflection of another aspect of jet inner structure. Therefore, with reasonable high transverse energy cuts, high-order MTEC functions can be used to study in detail both minijet and high energy jet inner structure, and can signify validly minijet production in $\sqrt{s} = 1.8$ TeV $p\bar{p}$ minimum biased collisions.

Now, concluding remarks are given bellow. First, new observables, *i.e.*, the MTEC functions are proposed to study minijet production in high energy $p\bar{p}$ collisions. As probes of jet inner structure high-order MTEC functions are shown to be more sensitive and more complete than 2-particle transverse energy correlation function. Second, using the MTEC functions, the possibility of detecting minijet production in minimum biased $\sqrt{s}=1.8$ TeV $p\bar{p}$ collisions has been studied with a Monte-Carlo model. It is demonstrated that minijet production can clearly be signaled by enhancement of high-order MTEC functions near the region of $U_N = 1$, especially when the functions are calculated with higher transverse energy cuts. Compared with the multi-particle transverse momentum correlation functions, which can be obtained with the CDF detector now at FERMILAB for 1.8 TeV $p\bar{p}$ collisions, the MTEC functions can be obtained not only with CDF but also with the D0 detector. Therefore, using the high-order MTEC functions, detection of minijet production in minimum biased 1.8 TeV $p\bar{p}$ collisions can be expected at FERMILAB in the near future, and a crosscheck on the study of minijet production with the two mentioned detectors is enabled.

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